



Review

Frequency re-use and the implications of limited network resources in cellular mobile systems

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A cellular network is used by the mobile telephone operators to achieve both coverage and capacity for their subscribers. Large geographic areas are split into smaller cells to avoid line-of-sight signal loss and to support a large number of active phones in that area. All of the cell sites are connected to exchanges (or switches), which in turn connect to the public switched telephone network. The demand for mobile services has been rising exponentially. However, the bandwidth and frequency spectrum to support these mobile services is critically limited. To address the competition for scarce resources, GSM service providers need new tools to help them efficiently and effectively optimize their networks. Several methods have been suggested such as cell splitting, frequency re-use, dynamic channel allocation or alternative routing, and adaptive cell-sizing algorithm. All these methods often imply either an increase in system complexity or a significant degradation of the quality of service. In this paper the frequency re-use techniques and implications of limited network resources are discussed.

Keywords: Base station, frequency planning, increased capacity, coverage area.

INTRODUCTION

The demand for mobile services has been rising exponentially. However, the bandwidth and frequency spectrum to support these mobile services is critically limited. To address the competition for scarce resources, GSM service providers need new tools to help them efficiently and effectively optimize their networks. Several methods have been suggested such as cell splitting, frequency re-use, dynamic channel allocation or alternative routing, and adaptive cell-sizing algorithm. All these methods often imply either an increase in system complexity or a significant degradation of the quality of service (Aloo and Von Wyk). The principle of frequency re-use arises from the fact that each cell is assigned a

group of channels. Frequency re-use is a fundamental concept in cellular radio systems, but such systems need careful planning to avoid degradation by co-channel interference, i.e. interference with calls in one cell caused by a transmitter in another cell that uses the same set of frequencies. Frequency re-use is therefore the fundamental target of cellular radio systems, and implementing this to maximum effect has been the subject of much study since the inception of the cellular principle (Cellular Networks , 2011). Frequency spectrum is a scarce or limited resource. Wireless network operators often have to compete in acquiring licenses to operate on any frequency of their choice. But the key characteristic of a cellular network is the ability to re-use frequencies to increase both coverage and capacity.

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Cellular networks

A cellular network is a radio network distributed over land areas called cells, each served by at least one fixed-location transceiver known as a cell site or base station. When joined together these cells provide radio coverage over a wide geographic area. This enables a large number of portable transceivers (e.g., mobile phones, pagers, etc.) to communicate with each other and with fixed transceivers and telephones anywhere in the network, via base stations, even if some of the transceivers are moving through more than one cell during transmission. An example of a simple non-telephone cellular system is an old taxi driver's radio system where the taxi company has several transmitters based around a city that can communicate directly with each taxi (Cellular Networks, 2011).

The concept of frequency re-use in cellular network

A cellular network is a mobile network that provides services by using a large number of base stations with limited power, each covering only a limited area. This area is called a cell. The limited power makes it possible to re-use the same frequency a few cells away from the base station without causing interference. In this way a geographic large area can be covered with only a limited set of frequencies. A cellular network is a very efficient manner of using the scarce frequency resources. The objective of frequency re-uses and channel assignment scheme is to minimize the call-blocking and the call-dropping probabilities. (Hale, 1980)

The size of a cell can vary according to the number of users that have to be served in a certain area and the amount of traffic per user. If there is much traffic in an area the cell size will be smaller than in rural areas. The key characteristic of a cellular network is the ability to re-use frequencies to increase both coverage and capacity. As described above, adjacent cells must utilize different frequencies; however there is no problem with two cells sufficiently far apart operating on the same frequency. The elements that determine frequency re-use are the re-use distance and the re-use factor. The re-use distance, D is calculated as:

$$D = R\sqrt{3N},$$

Where R is the cell radius and N is the number of cells per cluster. Cells may vary in radius in the ranges (1 km to 30 km). The boundaries of the cells can also overlap between adjacent cells and large cells can be divided into smaller cells. The concept of frequency-reuse is given in the figure1. The total amount of frequencies in this case is divided into 7 sets of frequencies. Each set is used in another cell. The cluster of 7 cells is repeated to cover the complete geographic area. Frequency re-use is a defining characteristic of cellular systems. In frequency re-use, the same carrier frequencies are used in multiple, geographically different areas for which the

system provides coverage. Significantly, these areas are separated from one another by a sufficient distance so that any co-channel or adjacent channel interference is less than a particular threshold.

The problem with a frequency reuse of one is the high level of inter-cell interference, i.e., interference originating from neighboring cells. To reduce inter-cell interference, FDMA and TDMA cellular systems typically use a frequency reuse greater than one, which means that neighboring cells use different carrier frequencies.(www.wirelesscommunication.nl/reference/chaptr04/.../reuse.htm)

In a cellular radio system, a land area to be supplied with radio service is divided into regular shaped cells, which can be hexagonal, square, circular or some other irregular shapes, although hexagonal cells are conventional. Each of these cells is assigned multiple frequencies ($f_1 - f_6$) which have corresponding radio base stations. The group of frequencies can be reused in other cells, provided that the same frequencies are not reused in adjacent neighboring cells as that would cause co-channel interference. The increased capacity in a cellular network, compared with a network with a single transmitter, comes from the fact that the same radio frequency can be reused in a different area for a completely different transmission. If there is a single plain transmitter, only one transmission can be used on any given frequency. Unfortunately, there is inevitably some level of interference from the signal from the other cells which use the same frequency. This means that, in a standard FDMA system (Cellular Networks , 2011), there must be at least a one cell gap between cells which reuse the same frequency. In the simple case of the taxi company, each radio had a manually operated channel selector knob to tune to different frequencies. As the drivers moved around, they would change from channel to channel. The drivers knew which frequency covered approximately what area. When they did not receive a signal from the transmitter, they would try other channels until they found one that worked. The taxi drivers would only speak one at a time, when invited by the base station operator (in a sense TDMA).

Movement from cell to cell and handover

In a primitive taxi system, when the taxi moved away from a first tower and closer to a second tower, the taxi driver manually switched from one frequency to another as needed. If a communication was interrupted due to a loss of a signal, the taxi driver asked the base station operator to repeat the message on a different frequency. But in a cellular system, it is different.

In a cellular system, as the distributed mobile transceivers move from cell to cell during an ongoing continuous communication, switching from one cell frequency to a different cell frequency is done electronically without interruption and without a base

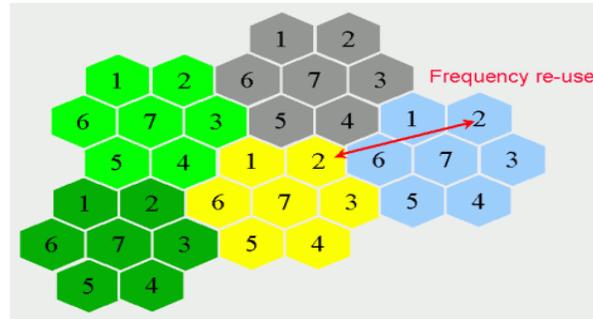


Figure 1. Diagrammatic Illustration of Frequency Reuse

station operator or manual switching. This is called the handover or handoff. Typically, a new channel is automatically selected for the mobile unit on the new base station which will serve it. The mobile unit then automatically switches from the current channel to the new channel and communication continues. The exact detail of the mobile system's move from one base station to the other varies considerably from system to system (Cellular Networks, 2011). The most common example of a cellular network is a mobile phone (cell phone) network. A mobile phone is a portable telephone which receives or makes calls through a cell site (base station), or transmitting tower. Radio waves are used to transfer signals to and from the cell phone. Modern mobile phone networks use cells because radio frequencies are a limited, hence they share resource. Cell-sites and handsets change frequency under computer control and use low power transmitters so that a limited number of radio frequencies can be simultaneously used by many callers with less interference.

Example of a cellular network: the mobile phone network

A cellular network is used by the mobile phone operator to achieve both coverage and capacity for their subscribers. Large geographic areas are split into smaller cells to avoid line-of-sight signal loss and to support a large number of active phones in that area. All of the cell sites are connected to telephone exchanges (or switches), which in turn connect to the public telephone network. In cities, each cell site may have a range of up to approximately $\frac{1}{2}$ mile, while in rural areas; the range could be as much as 5 miles. It is possible that in clear open areas, a user may receive signals from a cell site 25 miles away. Since almost all mobile phones use cellular technology, including GSM, CDMA, and AMPS (analog), the term "cell phone" is in some regions, notably the US, used interchangeably with "mobile phone". However, satellite phones are mobile phones that do not communicate directly with a ground-based cellular tower, but may do so indirectly by way of a satellite. There are a number of different digital cellular

technologies, including: Global System for Mobile Communications (GSM), General Packet Radio Service (GPRS), Code Division Multiple Access (CDMA) etc. A simple view of the cellular mobile-radio network consists of the following:

- A network of Radio base stations forming the Base station subsystem.
- The core circuit switched network for handling voice calls and text.
- A packet switched network for handling mobile data.
- The Public switched telephone network to connect subscribers to the wider telephony network (Cellular Networks , 2011).

This network is the foundation of the GSM system network. There are many functions that are performed by this network in order to make sure customers get the desired service including mobility management, registration, call set up, and handover. Any phone connects to the network via an RBS (Radio Base Station) at a corner of the corresponding cell which in turn connects to the Mobile switching center (MSC). The MSC provides a connection to the public switched telephone network (PSTN). The link from a phone to the RBS is called an uplink while the other way is termed downlink. Radio channels effectively use the transmission medium through the use of the following multiplexing schemes: frequency division multiplex (FDM), time division multiplex (TDM), code division multiplex (CDM), and space division multiplex (SDM). Corresponding to these multiplexing schemes are the following access techniques: frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), and space division multiple access (SDMA) (Cellular Networks , 2011).

Advantages of cellular networks

Cellular networks offer a number of advantages over alternative solutions:

- Increased capacity
- Reduced power use
- Larger coverage area

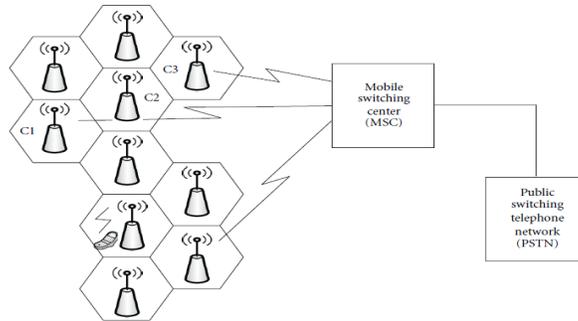


Figure 3. Example of typical cellular system architecture.

be assigned to two cells that are separated by a distance less than a specified minimum reuse, distance r_0 .

- Co-site constraint (CSC): channels in the same cell must be separated by a minimum amount g . That is, their radio frequencies must be far enough apart.

- Adjacent channel constraint (ACC): channels assigned to neighboring cells must be separated by a minimum amount.

Implications of limited network resources

The demand for mobile services has been rising exponentially. However, the bandwidth and frequency spectrum to support these mobile services is critically limited. To address the competition for scarce resources, GSM service providers need new tools to help them efficiently and effectively optimize their networks. Several methods have been suggested such as cell splitting and frequency re-use dynamic channel allocation or alternative routing, and adaptive cell-sizing algorithm (Aloo and Von Wyk). All these methods often imply either an increase in system complexity or a significant degradation of the quality of service. Hence, we will be considering the implication of limited network resources as follows:

Alteration in call tariffs

To address the competition for scarce resources, an approach out of many is to attempt to modify user demands to fit within the available network resources in the cell. Currently, most mobile service providers have implemented static pricing strategies by offering cheaper (or free) off-peak calls as a marketing incentive, in an attempt to utilize the spare capacity. However, a major drawback of the current tariffs is their lack of flexibility and inability to take account of the actual network load or the status of the network resources, by merely increasing the tariffs when the operator anticipates high demand (Aloo and Von Wyk).

Co-Channel interference

Co-channel interference is the radio interference caused due to the allocation of the same channel to certain pairs of cells with geographical separation not enough to avoid deterioration of signal quality. (www.wirelesscommunication.nl/reference/chaptr04/.../reuse.htm) The minimum distance required between the centers of two cells using the same channel to maintain the desired signal quality is known as the reuse distance (Wu and Jackal).

Power Requirement.

The fundamental selection criterion of transmission mode is the amount of Base Station (BS) power required to transmit to a group of MBMS users camping in that cell. As a Point-to-Multipoint transmission (Forward Access Channel {FACH}) needs cover the cell perimeter and be received by all the User Equipments (UEs) in the Cell, also those near the Cell's border, it requires more radio resources (**power**) than a Dedicated Channel (DCH). Therefore, few DCHs might outperform one FACH in terms of radio resource efficiency. Thus, in some cases where there are few MBMS users in the Cell it could be preferable to transmit the required service adopting P-t-P transmission using DCH's. However if we have a Cell with considerable number of Multimedia Broadcast Multicast Service (MBMS) users, establishing a common FACH for all users could in many ways be the best solution, since it requires less cell resources and decreases the transmit complexity in a way that the service is transmitted for all users in the cell in a unique common channel avoiding multiple transmissions of the same content (Christophorou and Pitsillides).

CONCLUSION

Consequent of producing this paper, based on the observation that there are handful of the implications of limited network resources and its attendant frequency reuse in cellular systems. It is also considered that some

of these implications could be viewed as an advantage or disadvantage to any cellular network. Some of these implications are alteration of call tariffs, power control, co-channel, scheduling, admission control, etc. few of these implications have been discussed in section 4. For call tariff alteration, It is intuitive that the trend of user demand can be modified by imposing higher rates during peak-traffic time periods and low rates when large network resources are available. Thus, this pricing scheme can be used as congestion control, call admission and resource management. For power control, it is dependent on if the services is provided either by point to multipoint (FACH) which is established and shared by all the User Equipments in the Cell or point to point (DCH) which is established for each User Equipment in the Cell (Christophorou and Pitsillides).

REFERENCES

"Cellular Networks" (2011). <en.wikipedia.org/wiki/Cellular_network>
(en.wikipedia.org/wiki/
en.wikipedia.org/wiki/Radio_resource_management) "Radio
Resource Management". <en.wikipedia.org/wiki/
en.wikipedia.org/wiki/Radio_resource_management>

Aloo P, Von Wyk MA. "Dynamic Pricing Control in Cellular Networks"
Tshwane University of Technology, Republic of South Africa. <
uir.unisa.ac.za/.../ICTeAfrica-.>
Christophorou C, Pitsillides A (YEAR) "Radio Resource Management
in MBMS Enabled 3G Mobile Cellular Networks: A New Handover
Control Approach". Department of Computer Science University of
Cyprus. <citeseerx.ist.psu.edu/viewdoc/download?doi
Falawo OE, Chan HA. "Radio Resource Management in
Heterogeneous Cellular Networks" Department of Electrical
Engineering, University of Cape Town, South Africa.
<www.intechopen.com/download/pdf/pdfs_id/14759>
(www.wirelesscommunication.nl/reference/chaptr04/.../reuse.htm)
"Principles of Cellular Frequency Reuse".
<www.wirelesscommunication.nl/reference/chaptr04/.../reuse.htm>
Hale WK (1980). "Frequency assignment theory and
applications".1497-1514, www.ieeexplore.ieee.org
X. Wu, A. Jackal, et al. "Optimized Hybrid Resource Allocation in
Wireless Cellular Networks with and without Channel
Reassignment". School of Computer Science, University of Windsor,
401 Sunset Avenue, Windsor, ON, Canada. <
downloads.hindawi.com/journals/jcsnc/2010/524854.pdf >